Launch Vehicle Health Management
An Overview

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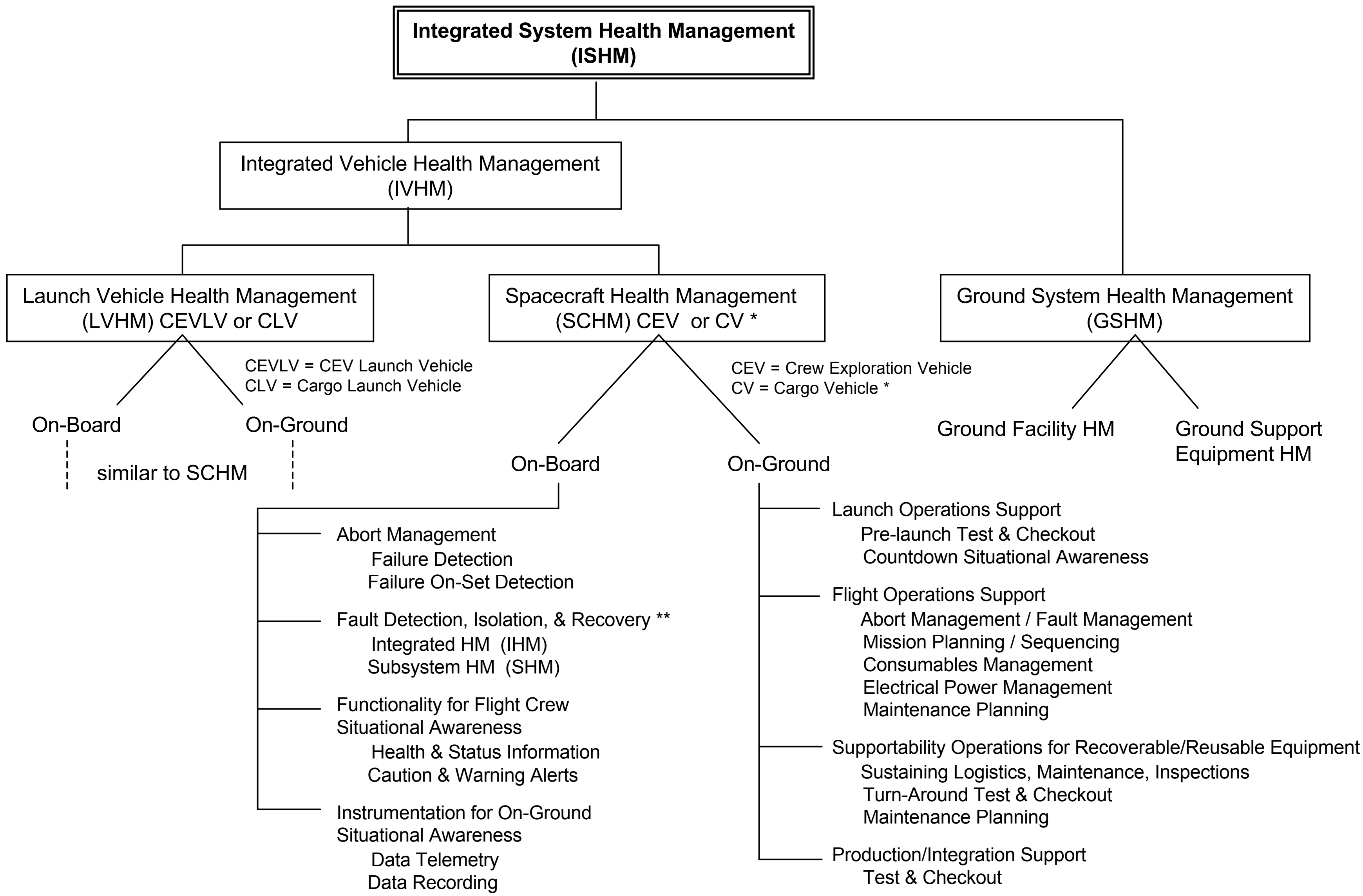
LVHM Basic Concepts

- Evolving from single discipline instrumentation based measurement systems to interdisciplinary and integrated health management systems that combine fault detection with health assessment and display, operational flight control, and operational launch preparation / maintenance control

- 2 separate areas of emphasis:
  - supporting operational readiness and sustainability
  - supporting the safety and effectiveness of operational flight

- “management” aspects of LVHM are generally organized and structured under conventional programmatic entities (flight/subsystem control, mission/maintenance management)

- “monitoring” aspects of LVHM, generally recognized as data acquisition, instrumentation, and measurement processing, are programmatically organized under Systems Health Monitoring
  - subsystem specific (e.g. Engines)
  - non-subsystem specific (Integrated System)



* may be a Transfer Vehicle (TV) for small to medium size payloads or a self-contained Space Vehicle, such as an Earth Departure Stage (EDS) or Lunar Surface Access Module (LSAM), that comprises a large payload
** includes Redundancy/Reconfiguration Management with or without human-in-the-loop

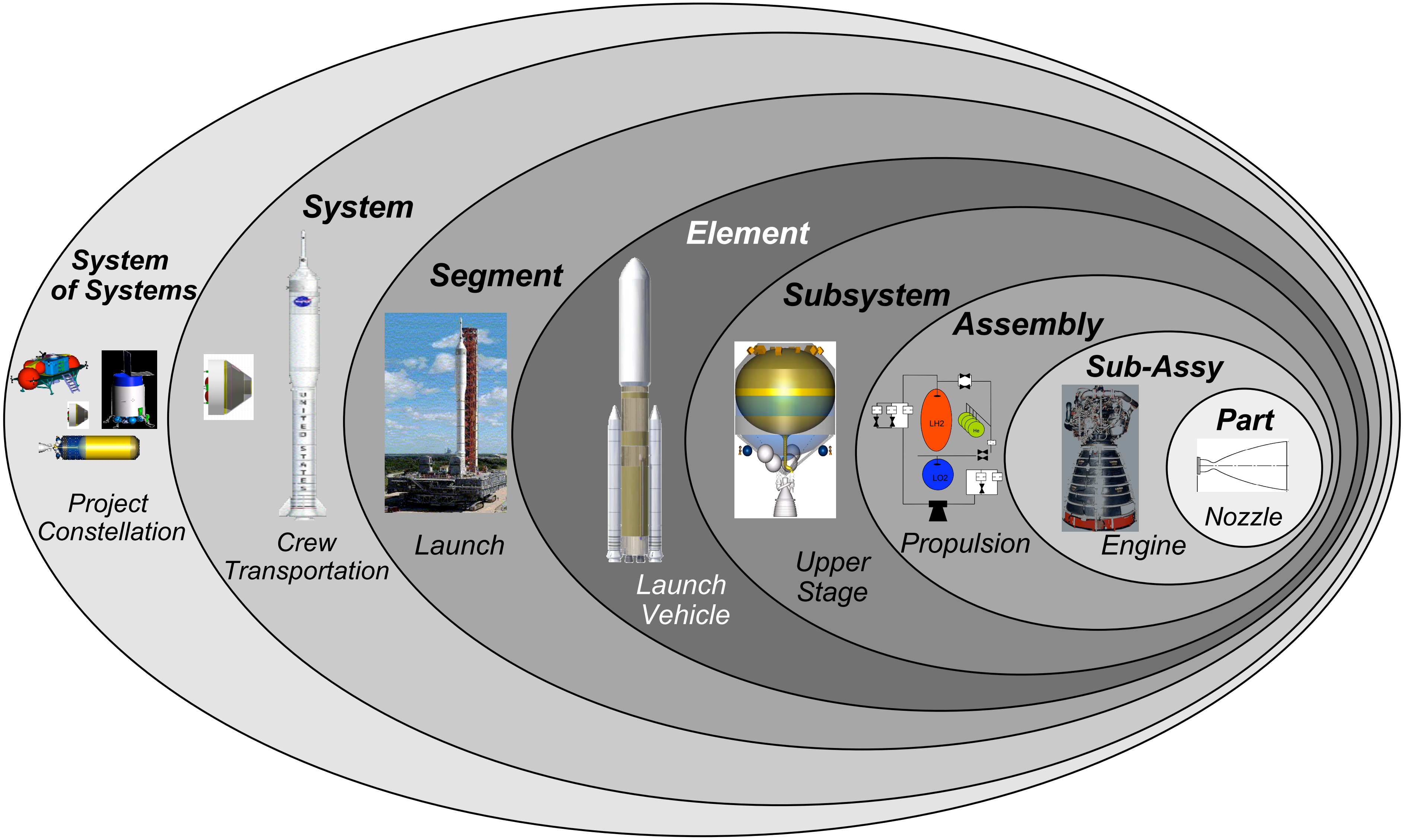
Elements in the Space System Launch Segment

- **Launch Vehicle**
  - Booster Stage
  - Upper Stage
- **Ground Based Launch / Mission Support Infrastructure**
  - Sustaining Engineering / Manufacturing / Operations
  - Pre-launch Integration & Test / Readiness
  - Launch Control
  - Mission Control
- **Payload**
  - Satellites / Space Probes
  - Crewed Transport Spacecraft
  - Construction & Structural Members
  - Surface Landers / Habitats
  - Propulsion Stages / Fuel Depots
  - Transfer / Cargo Vehicles

When ISHEM is employed in this segment, the aspects related to the Launch Vehicle and the Ground Based Launch/Mission Support Infrastructure up until Payload Deploy during operational flight, is known as LVHM

Design Drivers

- Reusable / Expendable
- Human / Cargo Payload
- Level of Responsiveness
- Payload Size / Value



NASA Architectural Terminology (images representational)

Systems Health Monitoring

The monitoring component of LVHM is called Systems Health Monitoring (SHM)

- An integrated data monitoring function devoted to collecting, processing, and distributing meaningful health & status data to interested users
- Includes both ground/flight critical data and maintenance/readiness data.
- Functionality generally resides on the ground

The onboard sensing, conditioning, multiplexing, modulation, and telemetric transmission of qualitative and quantitative, discrete and continuous health related data, is functionality that is assigned to the Avionics and Instrumentation subsystems

- physical sensors are usually owned by the subsystem in which they are resident

Fault detection functionality is often implemented both onboard and on-ground to varying levels depending upon whether or not digital controllers/computers are incorporated in the design

- diagnostic testing (redline/threshold comparison, model/rule based reasoning)
- loss of signal/data testing
- software testing
- algorithmic bit error checking

LVHM Functional Partitioning

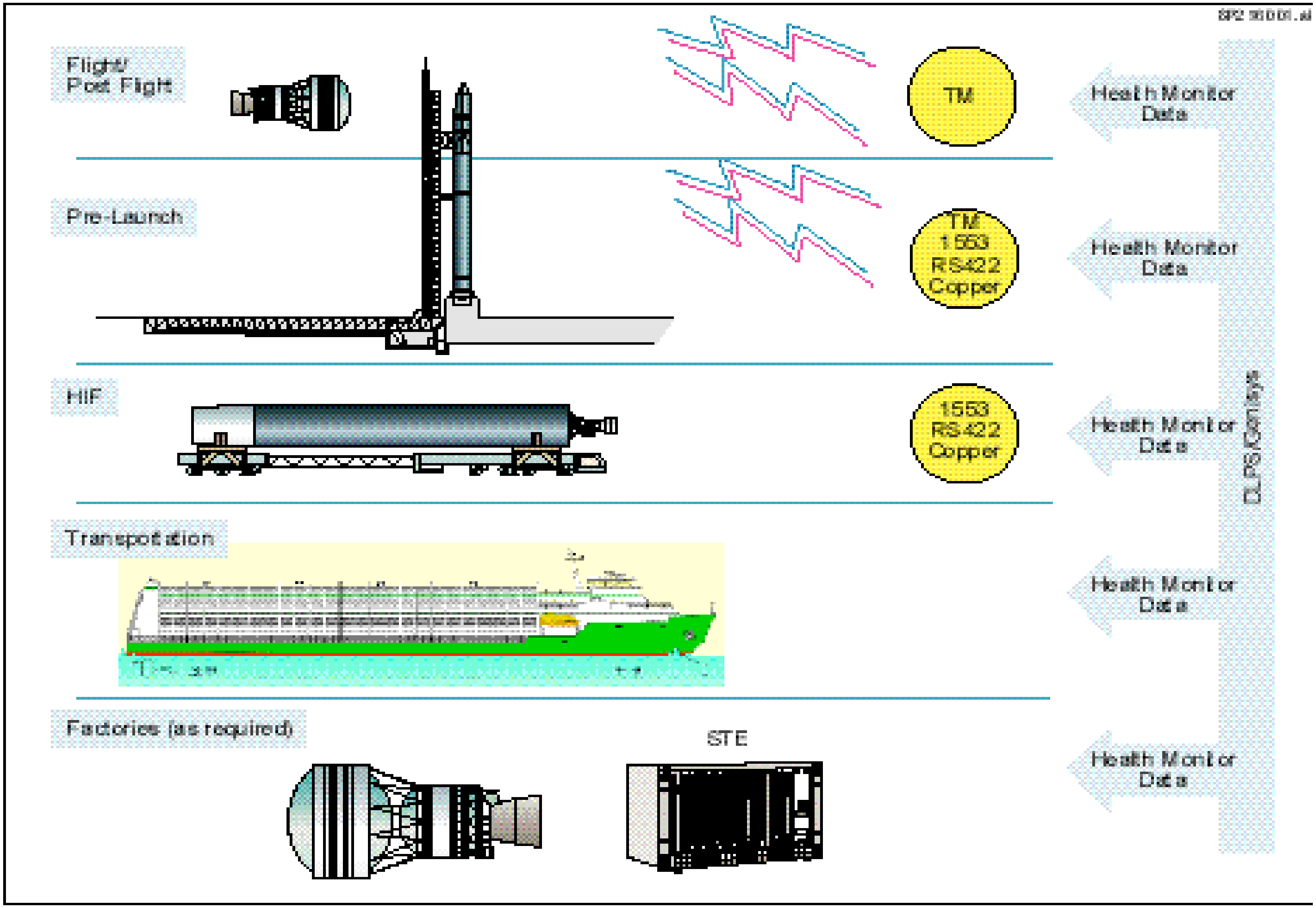
Monitoring of Critical Functions (Onboard and On-ground)
- Flight Critical
- Launch Critical

Monitoring of Non-critical Functions (Onboard and On-ground)
- Maintenance
- Readiness
- Situational Awareness

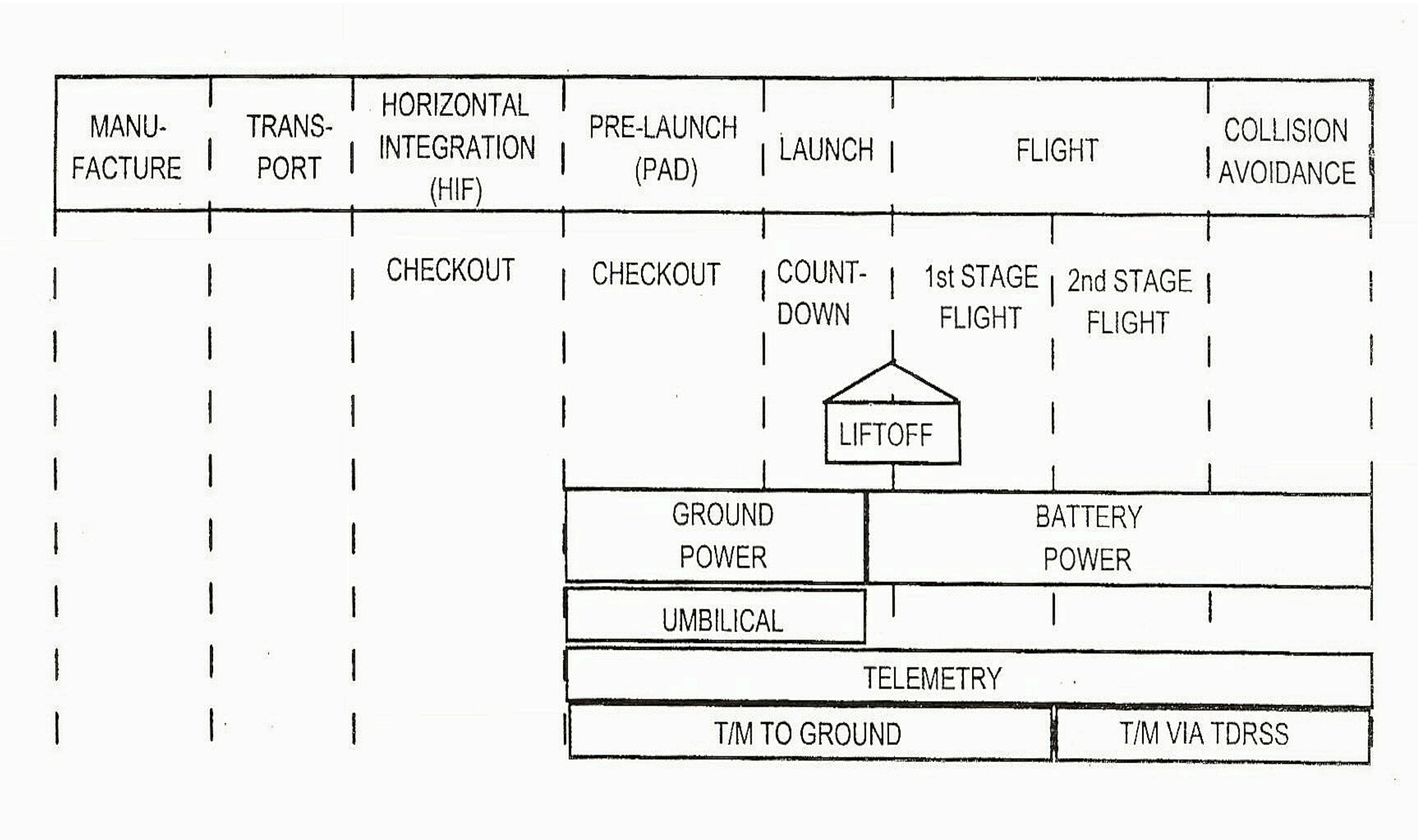
On-ground Processes (Critical and Non-critical Functions)
- Sustaining Engineering / Manufacturing / Operations
- Pre-launch Integration & Test / Readiness
- Launch Control
- Mission Control

Onboard Processes (Critical and Non-critical Functions)
- Avionics (Flight Control) Computer
- Subsystem Controllers (e.g. Engine)
- Telemetry / Instrumentation Processors and Sensors
- Health Monitor Computer

SHM Life-Cycle Data Flow



SHM Life-Cycle Profile



Support All Operational Phases

Day of Launch

- Scrub avoidance
- High visibility into all critical items
- Autonomous Loading
- Autonomous Go-No Go Support

On-orbit

- Checkout
  - Periodic
  - Availability
    - Dormant systems/subsystems
  - Data quality
  - Sensor status
- FDIR
  - Non BIT/BIT fault detection
  - Trending
  - Event correlation
- Reconfiguration
  - Physical/electrical isolation
  - Resource/schedule management
- Certification
  - Confidence factor
  - Ready to Go Next Time
- Maintenance planning
  - Snapshots
  - TSMD
  - Data recorders
  - Logistics impact alerts
  - Facilities
  - Test Equipment
  - Spares
  - Personnel
  - Significant Event Report

Development and Ground Processing

- Anomaly resolution
- Checkout
  - Vehicle in launch configuration
  - Depot - recreation of environment
    - TSMD
    - Snapshots
    - Data Recorders
  - Ground interface
    - Umbilical and RF
    - In-situ LRU testability interface
  - Certification

Prelaunch

- Anomaly resolution
- Certification
- Launch with failures/degradations
- - confidence factor

Allocation of Fault Detection Processing

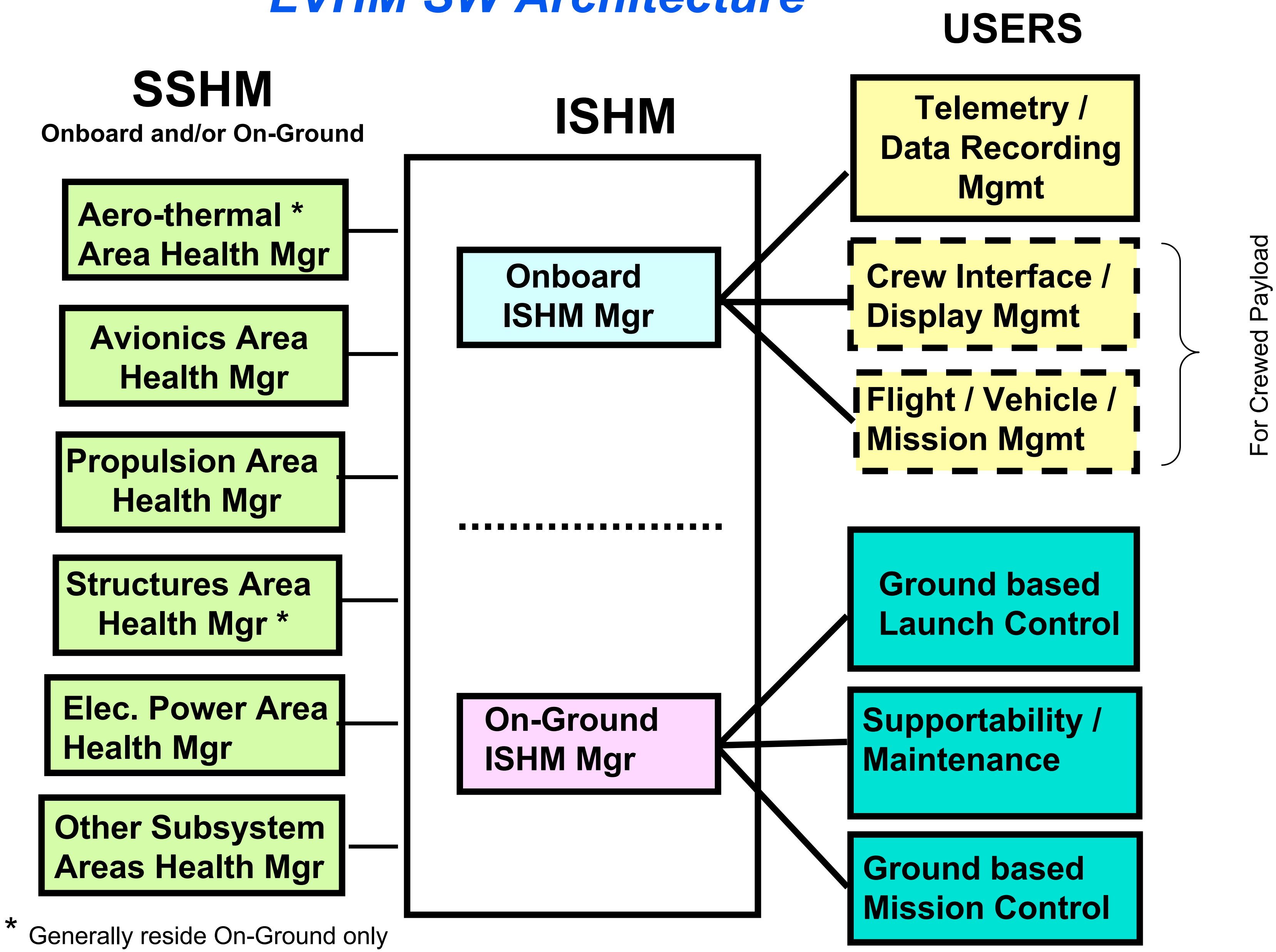
For quantitative continuous sensor data (and for discrete data that is generated by specific sensor types such as limit switches), when no subsystem controller/computer is involved:

- Fault detection processing generally occurs on-ground
  - Raw parametric data is sent to the ground by telemetry
  - Usual operational mode for non-critical flight data

For both qualitative and quantitative data, discrete and continuous, when subsystem control computers (or flight control computers) are involved that incorporate signal/data processing and Built-In-Test functionality:

- Fault detection processing may occur onboard or on-ground
- Telemetry of processed fault detection results may save telemetry bandwidth but it deprives the ground support engineering personnel of visibility into the actual physical state of the launch vehicle during the flight
  - They generally want access to all of the data and not just a pre-processed subset
    - especially true for critical flight data
    - also enhances the availability of investigative data in the unfortunate instance of an accident
- Telemetry of raw data places demands on the bandwidth and performance of the onboard instrumentation and communications subsystems
  - Size and update rate constraints on downlink telemetry
    - never enough bandwidth to satisfy everyone
    - design tradeoffs continually occur

LVHM SW Architecture



Measurements Management

Objective

- Identify and document all measurements necessary to detect and isolate failures
- Verify the success or failure of tests and operations performed

- Implemented with a concurrent engineering development tool and relational database

- Measurement Selection Criteria:
  - needed to detect faults and initiate corrective action as indicated by hardware failure modes identified in the Failure Modes, Effects, and Criticality Analysis (FMECA).
  - needed to support launch readiness
  - needed to perform an acceptance, integration, or pre-flight checkout test

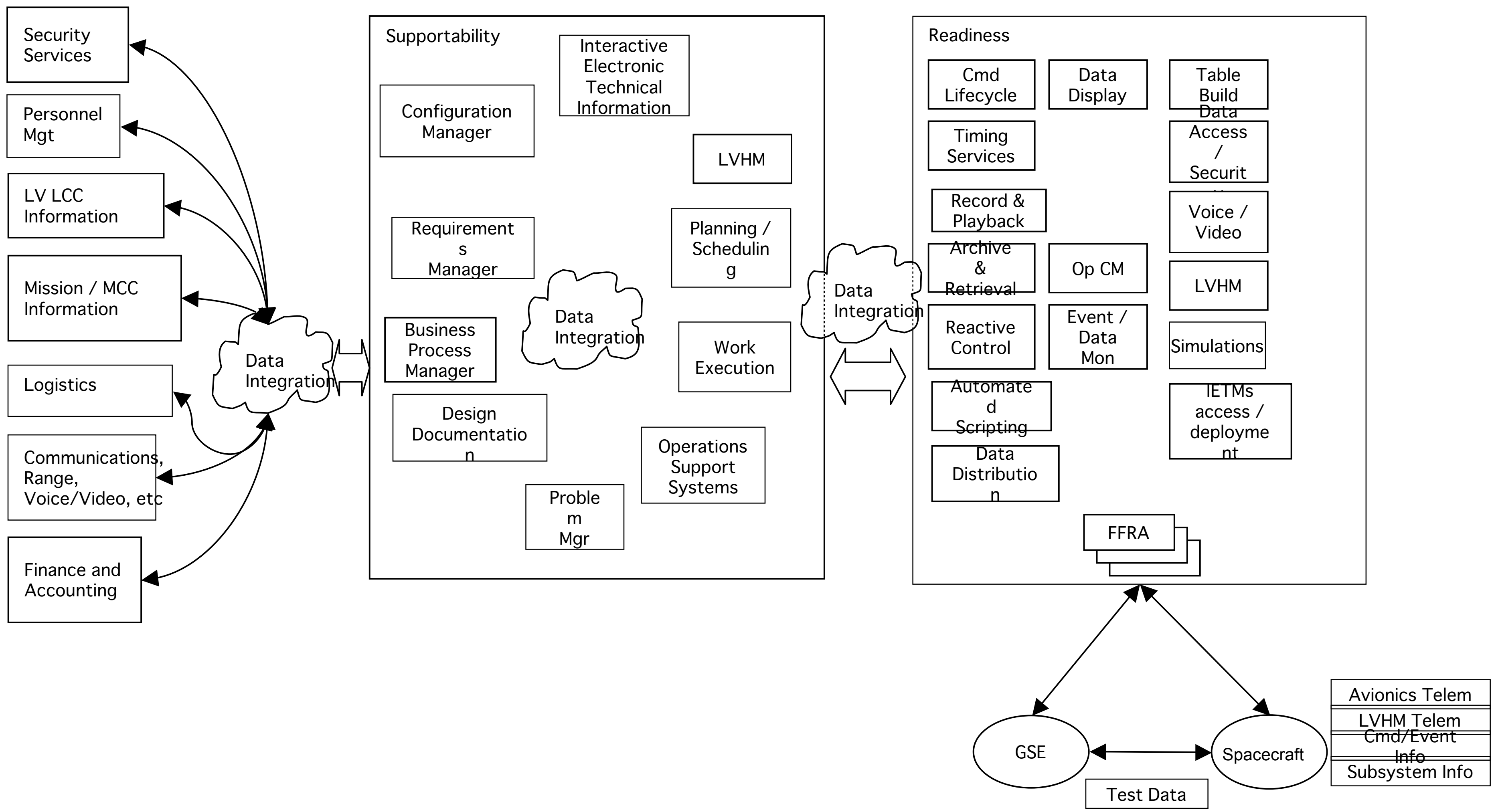
- Used for analytical evaluation and optimization exercises:
  - Failure mode detection coverage (FD)
  - Failure mode isolation to the LRU capability (FI)
  - Adequacy of telemetry throughput
  - Adequacy of software design
  - Adequacy of avionics throughput
  - Adequacy of ground data handling systems throughput

On-Ground SHM Design

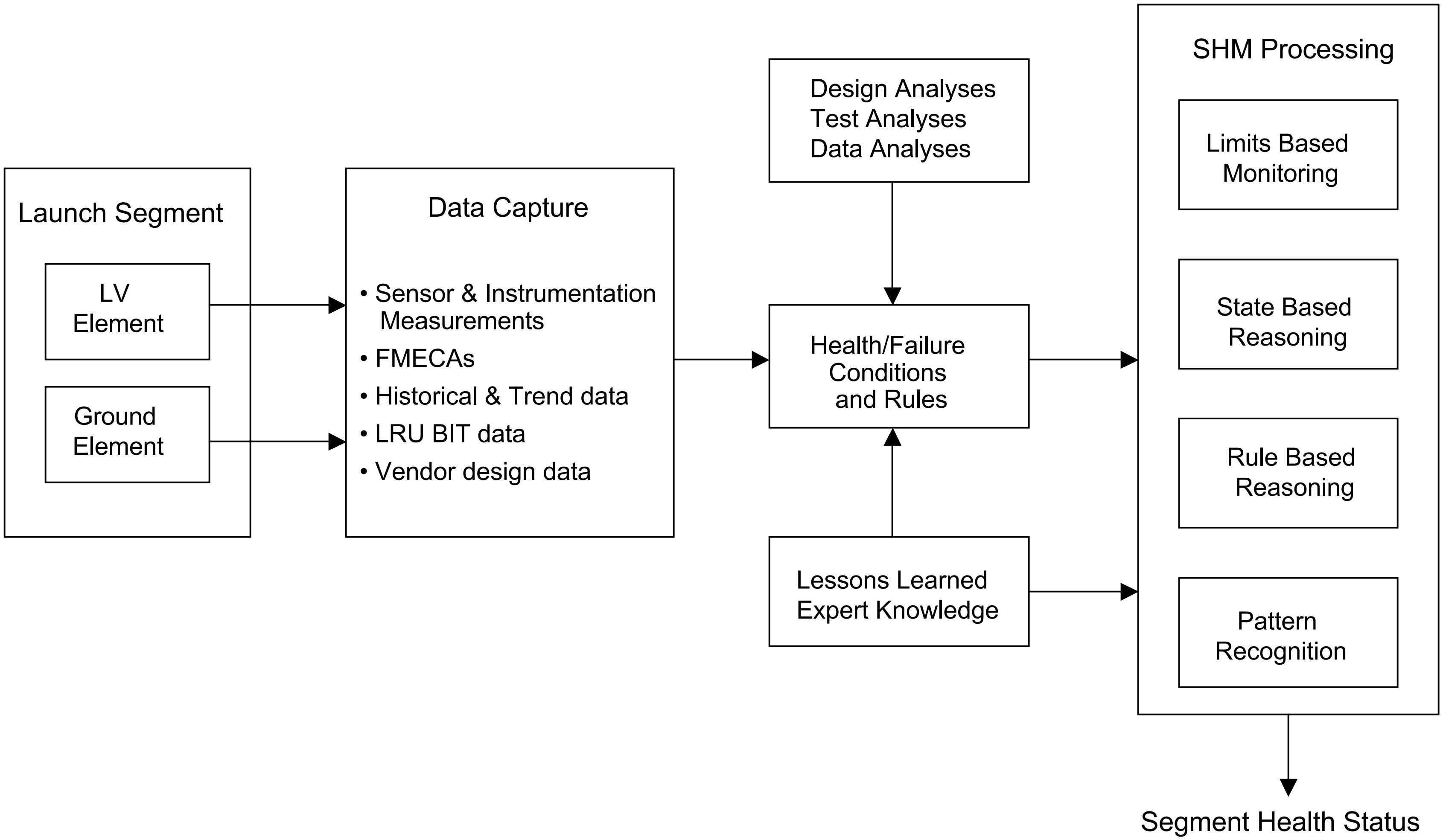
Approach:
Establish a health "baseline" in the on-ground launch support infrastructure "element", by enhancing the use of onboard Built-In-Test (BIT) capability, and thereafter identify deviations from the "baseline" as represented by operational instrumentation and continuous background test (by electronic computer / controller equipment)

- Power-On BIT
  - One time comprehensive foreground test
  - Verify functionality prior to transition to normal processing
- Periodic Monitoring BIT
  - Verify functionality as a background test
  - Less comprehensive than Power-On BIT
  - May be continuous or intermittent
- Initiated BIT
  - One time comprehensive test, may interrupt normal processing
  - Initiated via external control, manual or automatic
- Initiated BIT – Memory Inspect
  - Real-time display of memory contents
- Maintenance BIT
  - Specialized mode to facilitate fault detection and isolation
  - Replaces normal processing – a separate program or routine
  - Provides control visibility via external source

On-ground LVHM Interacts with other Ground Processes



Approach to On-ground SHM Design



On-Ground SHM Analysis

From the system analysis standpoint, the SHM inputs are:

- Hardware data (hardware identification number, quantity, failure rates for ground and flight)
- Configuration data (relating the specific hardware to the as-used configuration)
- Mission information (whether ‘production’, ‘special flight’, or ‘other’)
- Phase information (one or more of ‘manufacturing’, ‘transportation’, ‘integration’, ‘pad’, ‘launch and flight’)
- FMECA information (modes, criticalities)
- Measurement information (identifies the measurements contributing to the detection of each failure mode)

and the SHM outputs are:

- FD metrics (the percentage of failure rate associated with detected faults)
- FI metrics (the percentage of failure rate associated with fault isolation to each level of ambiguity, i.e. to one, two, or ‘three or more’ replaceable units)

A documented step-by-step process provides the methodology and procedures for calculation of numerical FD and FI metrics. These metrics are failure-rate (_) based.

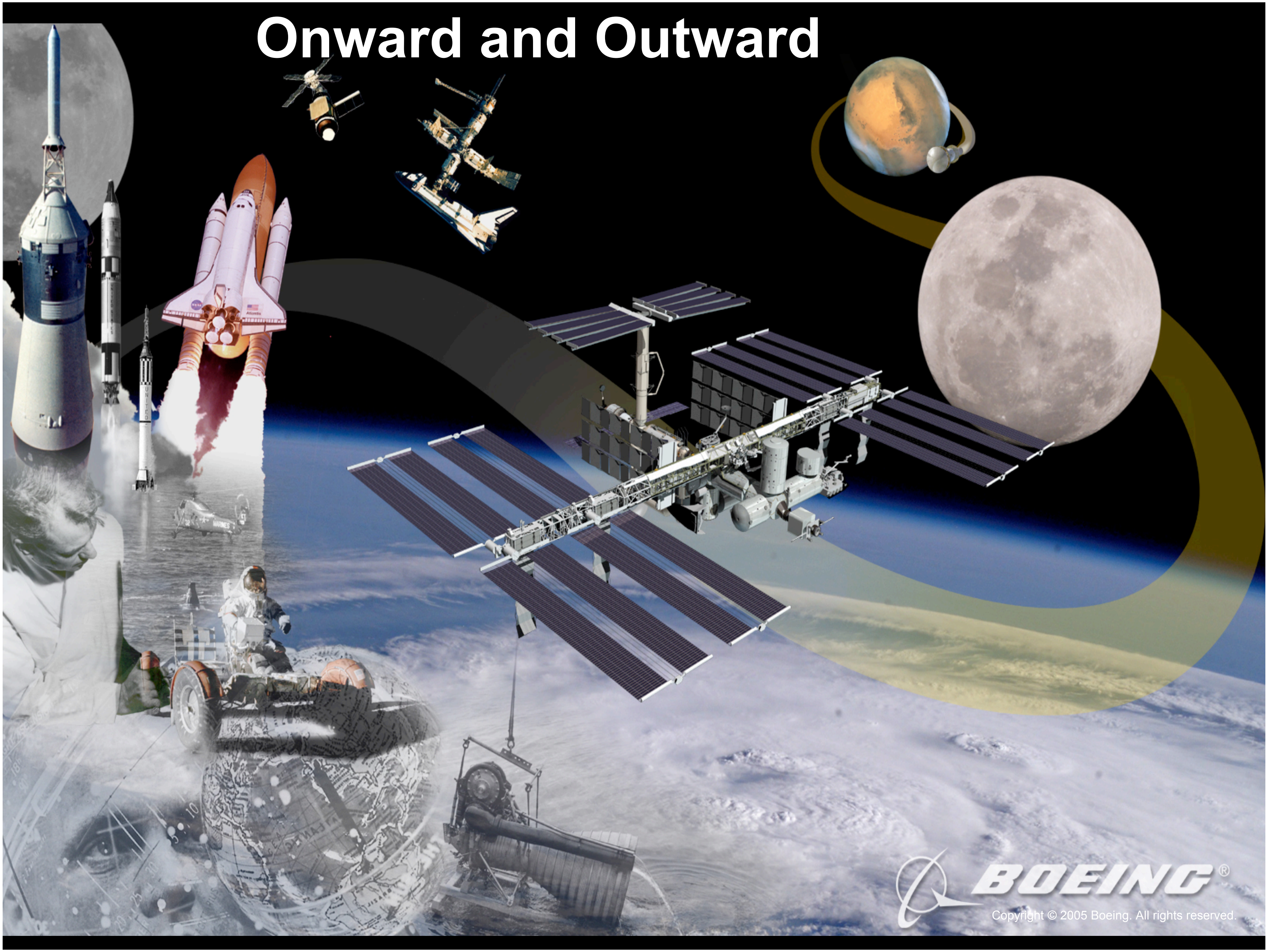
- FD metric is the ratio of $\_{detectable}$ to $\_{total}$ calculated at each level of the architectural hierarchy
- FI metric is the proportion of detectable failure rates associated with each level of fault isolation ambiguity - Low levels of ambiguity are highly desirable

Summary and Future Directions

All Launch "segments" require some form of SHM to help realize the goal of launching a perfect LV and payload into space. The vehicle processing and launch support team are focused on this goal, which includes:

- Ensuring that the LV and payload are ready for flight (no anomalies after system integration)
- Ensuring that the LV and payload remain fully functional during the pre-launch checkout and countdown
- Monitoring the health of the LV and payload during ascent flight (for post-flight reliability/maintenance purposes and for advising the operations team on possible recovery actions if anomalies are encountered during the flight)

To improve upon the effectiveness of these functions, it is generally accepted that a real-time determination of health state is highly desirable. To achieve this, more advanced capabilities in symptom detection, diagnosis, prognosis, and impact analysis are needed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